PART TIME: WVDP WASTE FORM QUALIFICATION REPORT - CANISTERED WASTE FORM SPECIFICATIONS

ITEM TITLE: SUBCRITICALITY SPECIFICATION

3.10 SUBCRITICALITY SPECIFICATION[(1)*]

The producer shall design a waste form that, under normal and accident conditions, a nuclear criticality accident is not possible unless at least two unlikely, independent, and concurrent or sequential changes have occurred in the conditions essential to nuclear criticality safety. The calculated effective neutron multiplication factor, k_{eff}, shall be sufficiently below unity to show at least a 5% margin after allowing for bias in the method of calculation and the uncertainty in the experiments used to validate the method of calculation. The producer shall describe the method of demonstrating compliance in the WCP and provide supporting documentation in the WQR. The WQR shall also include sufficient information on the nuclear characteristics, such as fissile density, of the canistered waste form to enable subcriticality to be confirmed under transportation, storage, and disposal conditions.

WVDP COMPLIANCE STRATEGY

The k_{eff} multiplication factor for the canistered waste will be calculated using the KENO[(2)] computer code. It will be shown that k_{eff} (which is defined below) is less than or equal to 0.90.

$$k_{eff(cal)} + 2|\sigma_{cal}| \leq 0.90$$

where:

σ_{cal} is the uncertainty and bias associated with method of calculation, and k_{eff} is the calculated effective neutron multiplication factor.

IMPLEMENTATION

Criticality analyses were performed at Pacific Northwest Laboratory to calculate the reactivity of the West Valley HLW glass canister in order to demonstrate compliance with this specification using their computer facilities[(7)]. The following canister configurations and fissionable material composition cases were analyzed:

Case 1) A single canister with optimally moderated glass and full water reflection.

Case 2) An infinite array of canisters with optimally moderated glass and no reflection.

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* The specification, as provided in Reference (1), is reproduced here in bold face print.

Case 3) An infinite array of canisters with optimally moderated glass with interstitial water moderation and reflection.

The fissionable material content of the glass was doubled (Double Batching) to establish conservative, worst case postulated accident condition. The double batching condition is consistent with the Double Contingency Principle[5,6] for criticality safety evaluations.

Optimum Moderation and Worst Case Reactivity Calculations

The SCALE code NITAWL-S[3] was used to prepare resonance self-shielded working cross section libraries from the SCALE 27 group master library. The one-dimensional discrete ordinates transport theory SCALE code XSDRNPM-S[4] was then used to calculate the k_{inf} of the waste form. XSDRNPM-S was also used to determine the reactivity which corresponded to optimum moderation[5] of the glass matrix. Based on the parametric analyses, a hydrogen to uranium ratio of 12 (H/U = 12) showed the highest calculated reactivity. The normal glass composition with maximum 0.15[8] weight percent water content gives an H/U = 0.08, a very highly under moderated matrix.

Canister Reactivity Calculations

The canister reactivity calculations were performed using the KENO-VA computer code[2] with increased fissile material contents (i.e., double batching) and assumed optimum moderation [i.e., H/U = 12]. The calculational statistics are based on 30,000 neutron histories. The analyses were performed for an optimally moderated canister, under various canister storage geometries. The results of these calculations are shown in Table 1. As expected, given the large boron content of the glass and relatively small quantities of the fissionable oxides, the calculated effective neutron multiplication factors are significantly below the 0.90 [i.e., $(k_{eff(cal)} + 2|\sigma_{cal}|)_{max} = 4.90E-3 < 0.90$] value required by the Waste Acceptance Product Specifications. Tables 2 and 3 show the major oxides and fissionable material composition used in the criticality analysis of the glass matrix. All calculations were performed using twice (2) the fissionable material inventory as indicated in Table 1.

Conclusion

The calculated canister reactivities, using the above conservative assumptions (increased fissile material inventory, optimum moderation, and infinite array configuration of canisters), indicate the glass and fissionable material mixture is extremely unreactive. This is due to the inherently low fissile material content in the glass matrix and the high concentration of other neutron absorbing material (e.g., boron content) in the glass. Therefore, it is concluded that the canistered vitrified glass waste will remain subcritical under all anticipated storage and transportation conditions.

DOCUMENTATION

No further documentation is required to comply with this specification.

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Table 1

KENO-Va Calculated Reactivities Assuming Double the Nominal Fissile Material Content [Double Batching][a]

Case[b] Number	Matrix	$k_{eff} + \sigma$	$k_{eff}+2\sigma$	Canister Analyses Conditions
1	Single canister containing optimally moderated glass	3.91E-3±1E-5	3.92E-3	Fully water reflected
2	Infinite array of canisters (2 foot center to center; touching) optimally moderated glass	4.88E-3±1E-5	4.89E-3	Air interstitial
3	Infinite array of canisters (2 foot center to center; touching) optimally moderated glass	4.31E-3±1E-5	4.32E-3	Water interstitial
3	Infinite array of canisters (2 foot 2 inch center to center) optimally moderated glass	3.98E-3±1E-5	3.99E-3	Water interstitial
3	Infinite array of canisters (2 foot 4 inch center to center) optimally moderated glass	3.96E-3±1E-5	3.97E-3	Water interstitial

(a) The fissionable material content of the glass was increased by a factor of 2 above those listed in Section 1.1, Table 9 of the West Valley Waste Form Compliance Plan[1].

(b) Refers to cases analyzed.

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Table 2

Glass Composition Used for Criticality Analysis

OXIDE	MASS (Kg)	WEIGHT PERCENT
Ag_2O	0.0028	
Al_2O_3	121.9135	6.510%
B_2O_3	188.0605	10.042%
BaO	0.2005	
CaO	9.3206	0.498%
CdO	0.0040	
Ce_2O_3	1.7209	
Cm_2O_3	0.0016	
CoO	0.0048	
CuO	1.1992	
Fe_2O_3	225.9315	12.064%
Gd_2O_3	0.0066	0.0004%
K_2O	69.5317	3.713%
Li_2O	58.7198	3.136%
MgO	16.7771	0.896%
MnO	18.6412	0.995%
NaF	3.1468	
Na_2O	212.8826	11.368%
Na_2SO_4	3.7579	
Nd_2O_3	1.8878	
NiO	4.6876	
P_2O_5	43.9933	2.349%
PuO_2	0.1461	0.008%
RuO_2	1.4707	
SiO_2	808.0965	43.151%
ThO_2	66.7371	3.564%
UO_2	10.7311	0.573%
ZrO_2	3.1572	0.169%
Total	1872.7 Kgs	99.035%
Moderated with H_2O (Maximum) [8]		0.15%

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TABLE 3

FISSILE MATERIAL INVENTORY FOR WVNS CANISTERS

FISSILE NUCLIDE	TOTAL Ci/CANISTER*
233-U	3.18E-02
235-U	3.03E-04
239-Pu	5.50E+00
241-Pu	3.15E+02
242-Am	1.00E+00
244-Cm	2.89E+01

* Total curies per canister present in WVNS waste based on Table 9 in WVDP-185,[1] assuming 300 canisters produced.

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REFERENCES

†1. Waste Form Compliance Plan for the West Valley Demonstration Project High-Level Waste Form, WVDP-185.

2. "KENO-VA: Multigroup Monte Carlo Criticality Program with Super-grouping." SCALE: A Modular Code System for Performing Standardized Computer Analyses for Licensing Evaluation. N. M. Greene, and L. M. Petrie. 1983 NUREG/CR-0200, Vol. 2, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

3. "NITAWL_S: Scale System Module for Performing Resonance Shielding and Working Library Production." SCALE: A Modular Code System for Performing Standardized Computer Analyses for Licensing Evaluation. R. M. Westfall, L. M. Petrie, N. M. Greene, and J. L. Lucius. 1983 NUREG/CR-0200, Vol. 2., Oak Ridge National Laboratory, Oak Ridge, Tennessee.

4. "XSDRNPM_S: A One-Dimensional Discrete-Ordinates Code for Transport Analysis." SCALE: A Modular Code System for Performing Standardized Computer Analyses for Licensing Evaluation. N. M. Greene, and L. M. Petrie. 1983 NUREG/CR-0200, Vol. 2., Oak Ridge National Laboratory, Oak Ridge, Tennessee.

5. American National Standards Institute, Inc., ANS-8.1, 1983.

6. American National Standards Institute, Inc., N16.5, ANS-8.7, 1975.

†7. "Criticality Safety Evaluation of West Valley HLW Canisters," WVNS-DP-002, Rev. 1.

†8. "Evaluation of the Potential for Gas Pressurization and Free Liquid Accumulation in a WVDP Canister," WVNS-DP-001, Rev. 1.

† These references are required to demonstrate conformance with the WCP compliance strategy.

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WVNSCO RECORD OF REVISION

Rev. No.	Description of Changes	Revision On Page(s)	Dated
0	Original Issue	All	03/28/91
1	Per ECN #6714	1,2,4,5	08/25/93
2	Per ECN #6726	All	08/25/93
3	Document formerly issued as WVNS-WQR-001, Section 3.10 (engineering document). Changed to WVDP-186, WQR-3.10 (project document) per ECN #6991.	All	12/23/93
4	Revision made per Technical Review Group comments. Reference letters CD:94:0067 and CD:94:0070.	1,2,4,5,6	10/12/94
FC1	Text revision to first paragraph of Implementation section to clarify PNL's role.	1	06/30/95
5	Incorporation of PC1 and identification of key references.	6	08/14/96
FC1	Updated Specification to be consistent with current revision of WAPS.	1	10/03/01
	Reworded first sentence of WVDP Compliance Strategy.	1	
	Deleted revision number and date from Reference 1. No departments are impacted by this change	6	
6	This document is being placed on “INACTIVE” status. QA, Site OPS, and Infrastructure are impacted by this change	All	06/20/05